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AQUARIUM MAINTENANCE OF MESOPELAGIC ANIMALS: A PROGRESS REPORT

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Abstract: Literature and experiments in progress concerning the capture and aquarium maintenance of midwater fishes and invertebrates are discussed. The longevity and survival of mesopelagic animals captured in Monterey Bay, California, are tabulated, and those species which appear most suitable for aquarium captivity are identified. Certain mesopelagic species are insensitive to large changes in hydrostatic pressure and were maintained at ambient pressure with proper temperature and light controls.

Large public and private aquariums possess unique facilities which allow research opportunities unavailable to most universities and research laboratories. The immense water systems, water quality control and monitoring systems, and around-the-clock engineering capabilities utilized by large aquaria make them the most likely facilities at which the environment of a large aquatic ecosystem might be reproduced.

At the Steinhart Aquarium, we have attempted to investigate the behavior and natural history of animals living in the deep sea, perhaps among the most exciting of frontiers remaining in modern biology. Adaptation to life in the deep sea has resulted in fantastic and bizarre morphologies, the function of which has until recently been only inferred from preserved specimens. The development of submersibles has allowed the *in situ* observation of living deep sea animals (cf. Barham, 1966), however the goal of understanding the behavior and physiology of these creatures remains to be solved through their aquarium maintenance. The Steinhart Aquarium Midwater Maintenance Program (SAMMP), assisted by a grant from the Charline Breeden Foundation, is attempting to identify and solve the aquarium-related problems. The results of our pilot project and a review of pertinent studies relating to the aquarium maintenance of midwater animals form the basis of this report.

The Steinhart Aquarium project was conceived

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TABLE 1. Survival of deepwater fishes in captivity, various authors.

Species	Depth of Capture	Longevity	Cause of Death	Reference
Family Myctophidae				
Tarletonbeania crenularis	surface	72 hours	light leak	Robison, 1973
Myctophum nitidulum	surface	9 hours	overcrowding	Robison, 1973
Diaphus theta	surface	12 hours	net damage	Robison, 1973
Gonichthys coccoi	surface	36 hours	——	Beebe and Vander Pyl, 1944
Family Melamphaidae				
Poromitra crassiceps	>250 meters	8 hours	net damage	Robison, 1973
Family Bathylagidae				
Leuroglossus stilbius	>25 meters	24 hours	aquarium failure	Robison, 1973
Family Anoplogasteridae				
Anoplogaster cornuta	>600 meters	48 hours	net damage	Robison, 1973
	>600 meters	13 days	internal injuries	Childress and Meek, 1973
	>600 meters	23 days	internal injuries	Childress, pers. comm.
Family Berycidae				
Beryx splendens	200–800 meters	indefinite	——	Takeuchi, *et al.*, 1969
Family Himantolophidae				
Himantolophus groenlandicus	surface	8 days	thermal stress	Haneda, 1968

after discussions with Otis Barton, adventurer, engineer, developer of the Barton Midwater Trawl and accompanist of William Beebe in the 1930's bathysphere dives. Barton had prepared a film describing his experiments with a 10 m pipe-frame trawl and hyperbaric chamber of his own design. Trawling this large net at slow speed (< 3 km/hr) off the Kona Coast of Hawaii resulted in the capture of large specimens in exceptionally robust conditions, several of which were near the maximum recorded size of certain species (cf. Smith and Atz, 1973), as well as representing new capture records for the Pacific Ocean (Iwamoto, McCosker, and Barton, in press). By quickly placing the captured specimens in seawater barely above freezing, Barton has been able to maintain adult specimens of large ceratioids, whalefishes (*Barbourisia rufa*), and dragonfishes (stomiatoids), for extended periods of a day or more. Barton's dramatic results inspired us to further investigate the possibility of maintaining living specimens of deep sea animals in the Steinhart Aquarium.

Few literature references exist which discuss the survival of midwater animals in captivity. A brief review of previous studies concerning deep sea fish maintenance is found in Gordon (1970: 445–446). Summarized in table 1 are those studies which bear on our work.

Lanternfishes of the family Myctophidae are desirable candidates for aquarium maintenance because of their availability and their interesting bioluminescent organs. The universal difficulty, however, has been the tendency of lanternfishes to destroy themselves by plummeting and battering their bodies against the container walls. Certain species are more amenable to captivity, however, including those listed in table 1. Beebe and Vander Pyl (1944) maintained net-caught specimens of *Gonichthys coccoi* on shipboard for up to 36 hours. The durability of this species is evidenced by a specimen which Beebe named "Methuselah" that had survived being "subjected to all sorts of experiments, dropped on the floor twice, and placed for a moment by mistake in a bowl of formalin." Somewhat more careful treatment of myctophids has resulted in their maintenance for longer periods, particularly the work of Robison (1973) using a modified planktonkreisel (Greve, 1968) and surface-dipnetted specimens of *Tarletonbeania crenularis*, *Myctophum nitidulum*, and *Diaphus theta*. Lawry (1974) demonstrated the

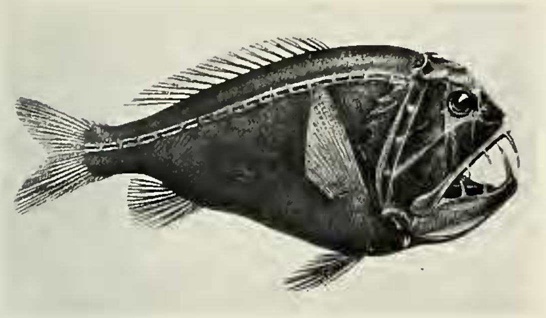

Figure 1. The bathypelagic Fangtooth *Anoplogaster cornuta*, a likely candidate for aquarium maintenance. (From Zugmayer, 1911.)

countershading function of ventral bioluminescence in live *Tarletonbeania crenularis*, however, he did not indicate their longevity in an aquarium.

Perhaps the most dramatic midwater animal that has been maintained to date is the bathypelagic Fangtooth *Anoplogaster cornuta*. This cosmopolitan species lives below 600 meters off Southern California (Berry and Perkins, 1965) and, although rare, it has been caught in approximately half of the midwater trawl runs in certain areas. Several authors have commented on its healthy condition after capture, and relate this to its lack of a gas-filled swimbladder (Fitch and Lavenberg, 1968). Childress and Meek (1973) have successfully kept living specimens aboard ship in 4 l nalgene jars at 5°C, later transferring them to 16 l cylindrical washbasins where they lived as long as 13 days. Childress (pers. comm.) has subsequently kept them in a similar manner for 23 days. Their observations of *Anoplogaster* feeding and swimming behavior made under weak red light were perhaps the first documentation of bathypelagic fish behavior. The same authors (Meek, 1973; Meek and Childress, 1973) were able to obtain oxygen consumption rates at atmospheric pressure and at 1000 psig (68 atmospheres). Their success in maintaining this species within the confines of a 16 l washbasin certainly suggests that with proper temperature controls, the midwater Fangtooth might be kept alive indefinitely in a large public aquarium.

The deepwater berycid *Beryx splendens* has been maintained for several months at Aburatsubo Marine Aquarium (Takeuchi, *et al.*, 1969). This near-benthic species, normally living at 200–800 m, adapted well to temperatures of 15–18°C and was found to prefer an illumination of 11.0 lux (within a range of 8–16 lux).

Certain ceratioid angler fishes are hardy species as evidenced by the fortuitous occurrence, capture, and study of a live *Himantolophus groenlandicus* (Haneda, 1968). Ceratioids have been kept alive for several days in shipboard aquaria (Bertelsen, pers. comm.), yet their scarcity has precluded their utilization as an experimental animal.

Many midwater fishes may be captured in near-perfect condition by taking advantage of their epipelagic distribution while juveniles. This is especially true for such desirable fishes as ceratioids and berycoids (cf. Mead, *et al.*, 1964). Robins and de Sylva (1965) described aquarium observations of juvenile *Gibberichthys pumilus* (as *Kasidoron edom*), a fascinating form with a spectacularly developed pelvic fin. Aquarium rearing of the juvenile forms through transformation could well occur and possibly aid in taxonomic studies such as the identification of disparate juvenile and adult forms.

Midwater-animal aquarium displays need not be limited to fishes. The cephalopods and crustaceans that inhabit the midwater environment are equally fascinating in their curious adaptations to existence in the deep sea, and some have proven to be more adaptable to aquarium conditions than fishes. By maintaining midwater squid (*Abraliopsis* sp.) in shipboard aquaria, Young and Roper (1976) were able to demonstrate the countershading function of squid bioluminescence. The large mysid shrimp *Gnathophausia ingens* living in the oxygen minimum layer off California, is a dramatic red crustacean that has evolved to the midwater habitat. Childress (1968, 1971) has studied the respiratory behavior of *G. ingens* under laboratory conditions and maintained them as long as 2½ years (pers. comm.). Other researchers have made use of the diurnal vertical migration of crustaceans; for example, Pearcy and Small (1968) captured and maintained *Euphausia pacifica*, *Thysanoessa spinifera*, and *Sergestes similis* at 100 m depth, the peak of their migration which often covers 500 m.

METHODS

The Steinhart Aquarium project, which officially began in March 1974, is at a stage where the feasibility of potential aquarium display species is being investigated. The results of our aquarium longevity studies are presented in table 2.

SAMMP animals were collected in Monterey

Table 2. Survival of mesopelagic and upper bathypelagic species in captivity, from SAMMP data.

Species	*n*	Temp (°C)	Depth of Capture (m)	Maximum Longevity
PISCES				
Family Scyliorhinidae				
Apristurus brunneus	2	8	500–600	2 days
Parmaturus xaniurus	3	11–15	400–500	15 days
Family Myctophidae				
Lampanyctus regalis	1	11	500–700	22 hours
Lampanyctus regalis	2	5.5	500	20 hours
Lampanyctus ritteri	3	8	500–600	6 hours
Stenobrachius leucopsarus	8	5.5	300	24 hours
Family Bathylagidae				
Bathylagus wesethi	1	5.5	400–500	20 hours
Leuroglossus stilbius	6	7	300–500	20 hours
Family Melanostomiatidae				
Bathophilus flemingi	1	7	400–500	8 hours
Tactostoma macropus	2	7	400–500	6 hours
Family Zoarcidae				
Lycodapus mandibularis	9	5.5	400–600	7.5 days
Lycodapus mandibularis	8	7	400–600	12 days
Lycodapus mandibularis	5	11	400–600	5 days
Melanostigma pammelas	21	5.5	400–600	4 months
Melanostigma pammelas	8	8	400–600	12+ months
Melanostigma pammelas	5	11	400–600	36 days
Family Liparidae				
Nectoliparis pelagicus	11	5.5	300–500	6 days
Nectoliparis pelagicus	8	8	300–400	21 days
Nectoliparis pelagicus	2	11	300–400	22 hours
Lipariscus nanus	4	7	500–600	20 hours
MOLLUSCA				
Gastropoda				
Clio pyramidata	2	8	200–300	24 hours
Pterotrachea sp.	1	7	400–500	45 hours
Cephalopoda				
Chiroteuthis calyx	1	5.5	350–500	3 days
Galiteuthis phyllura	9	7	300–500	9 days
Gonatus onyx	5	7	300–500	3 days
Histioteuthis heteropsis	1	5.5	300–500	2 days
Histioteuthis heteropsis	1	7	400–500	4 days
Japetella heathi	1	7	500–650	3 days
Octopoteuthis deletron	2	8	350–450	24 hours
Octopus sp.	2	5.5	350–400	3 days
Opisthoteuthis californiana	1	7	460–480	5 days
ARTHROPODA—CRUSTACEA				
Copepoda				
Gausia princeps	5	7	500–600	14 days
Pareuchaeta japonica	12	7	300–500	3 days
Amphipoda				
Hyperia medusarum	8	7	350–500	19 days
Lanceola sp.	2	7	200–400	7 days

TABLE 2. Continued.

Species	*n*	Temp (°C)	Depth of Capture (m)	Maximum Longevity
Orchomene obtusa	2	7	350–450	50 days
Paracallisoma coecus	1	5.5	300–550	20 days
Paraphronima crassipes	1	5.5	350–500	24 days
Phronima sedentaria	3	5.5	300–500	28 days
Scina sp.	2	5.5	350–500	19 days
Mysidacea				
Eucopia unguiculata	3	5.5	600–800	21 days
Boreomysis arctica	5	8	300	10 hours
Boreomysis california	6	7	400–600	9 hours
Gnathophausia ingens	2	7	500–600	2 days
Euphausiacea				
Euphausia pacifica	10	5.5	200–300	24 hours
Euphausia pacifica	16	8	200–300	3 days
Decapoda				
Bentheogennema burkenroadi	3	5.5	275–450	9 days
Pasiphaea pacifica	5	5.5	350–500	11 days
Pasiphaea pacifica	3	8	200–300	19 days
Sergestes similis	5	7	300–400	6 days

Bay, California. The oceanographic topography of the bay is characterized by a deep nearshore submarine canyon, providing favorable conditions for the collection and transport of midwater animals. Bimonthly collections were made from the Moss Landing Marine Laboratories (MLML) vessel R/V ST908, a 15 m converted harbor tug, utilizing a six foot (1.8 m) messenger-operated closing Tucker Trawl shortened to a length of 9 m. The flow-through, inverted-cone, canvas cod end (modified after Clarke, 1969) reduced the abrasion to captured animals. Short duration trawls also increased animal survival. Specimens removed from the net were placed in sea ice chilled, darkened plastic buckets. Experimentation with a planktonkreisel similar to that described by Robison (1973), with the expectation that it would reduce fish loss during transport, proved unproductive. Fishes were transferred to the MLML facility for study or temporary holding and kept in a 95 l darkened plastic container floated in refrigeration tanks, with maintained temperatures of 5.5, 7, or 8°C ± 0.5. The 11°C ± 1 system described in table 2 relates to the circulating system at the Steinhart Aquarium for the display of cold temperate and boreal marine fishes (Herald, 1963). The fishes were kept in a darkened 95 l tank and fed live brine shrimp (*Artemia salina*). Cephalopods were maintained in separate containers to prevent their ingestion of other animals.

RESULTS

From our data it is evident that certain species (e.g., *Melanostigma pammelas*) survive well at both 5.5°C and 11°C, while others tolerate only the colder system (e.g., *Lycodapus mandibularis* and *Nectoliparis pelagicus*). The Midwater Eelpout *Melanostigma pammelas* has thus far proven to be an exceptional display species. It is hardy, survives transport well, is not uncommon, and actively swims in the aquarium water column. Our specimens have fed heartily on live *Artemia* and, after approximately two weeks, have become "accustomed" to incandescent light. As an exhibit animal, this species is a superb example of the adaptation of a primarily benthic fish group (family Zoarcidae) to the midwater environment, exemplified by its large eyes, terminal mouth, black pigmentation, and swimming mode. Another midwater species which shows promise as an exhibit animal is the Tadpole Snailfish *Nectoliparis pelagicus*. Although small, this species is of interest in that it, like *M. pammelas*, represents a pelagic form derived from a benthic ancestor. Related deepwater zoarcids also amenable to captivity include the pelagic Pallid Eelpout *Lycodapus mandibularis* and the benthic eelpout *Maynea californica*. The Pallid Eelpout is more common than previously believed and survived for 12 days at 7°C. *M. californica*, although not a pelagic species, is an intriguing display animal and would

Figure 2. Living adult specimen of the midwater Eelpout *Melanostigma pammelas* in the Steinhart Aquarium.

be well suited for physiological research. Specimens trapped in 250 m by Richard Kliever of Moss Landing Marine Laboratories, who is presently studying the biology of *Maynea*, have fed and survived indefinitely at 11–15°C.

We have not actively pursued the maintenance of surface-dipnetted lanternfishes (family Myctophidae), but expect that through experimentation and improvement of Robison's (1973) technique, we should be able to solve the bugaboo of myctophid transport. We expect to permanently display myctophids in a rounded tank designed at the Steinhart Aquarium for the maintenance of fragile pelagic engraulids and clupeids. The problem of scale loss due to contact with the aquarium surfaces is common among these fishes and is solved by the action of a slow gyral circulation generated by the inflowing water.

The Filetail Cat Shark *Parmaturus xaniurus* has proven to be a dramatic display species. Juveniles of this species are extremely hardy and not uncommon in midwater trawl captures (Lee, 1969). Our maintenance of *Parmaturus* was incidental to the project and, in the absence of a suitable large refrigerated aquarium system, specimens were placed in an outdoor pool at MLML maintained with surface seawater. *P. xaniurus* is an instructive display species in that its large green eyes, black to brown coloration, and swimming mode are typical of the adaptations made by midwater sharks. Although uncommon, we suspect that the deep water sharks of the genera *Apristurus*, *Euprotomicrus*, and *Isistius* might also be suitable as aquarium species (Hubbs, *et al.*, 1967; Taylor, 1972).

We were successful, to a limited extent, with the maintenance of midwater cephalopods and crustacean. Midwater trawl-caught squid (*Galiteuthis phyllura*) lived as long as nine days in our 5.5°C system, finally expiring due to net damage and water circulation difficulties. Although intolerant of relatively small changes in water temperature, cephalopods were generally tolerant of exposure to subdued daylight. Mesopelagic crustaceans have survived well, as evidenced by Childress' (1968, 1971) studies on the mysid *Gnathophausia ingens*. Our specimens of *G. ingens* were infrequently captured and too damaged to allow their maintenance.

DISCUSSION

Several popular misconceptions exist concerning animals, particularly fishes, living in the deep sea. Prevalent is the belief that "fishes will 'explode' when brought up from great depths." This misconception is derived from the assumption that all fishes possess a gas or "swim" bladder which embolizes under hypobaric conditions. Nearly half of the midwater, benthic, or near-benthic fishes lack trapped air spaces (Denton and Marshall, 1958; Marshall, 1960) and are often brought up in healthy condition. The midwater environment in which our preliminary studies are directed is limited to the mesopelagic rather than the bathypelagic zone. Those fishes which do possess large gas bladders, as typified by the hatchetfishes of the genera *Sternoptyx* and *Argyropelecus*, are not suitable for live maintenance until suitable hyperbaric collecting and maintenance devices can be constructed. Certain desirable midwater species with gas bladders may be captured in healthy condition by taking advantage of their diurnal vertical migratory (DVM) behavior, particularly during the new moon (cf. Robison, 1973). Certain midwater species typically make daily vertical excursions of 1000 m, many reaching or approaching surface waters (Taylor, 1968; Marshall, 1971). Pressure effects on other physiological and anatomical systems are not obvious, although recent studies have shown that enzyme systems behave differently under hyperbaric conditions (Hochachka, *et al.*, 1970; Moon, *et al.*, 1971a, 1971b). In experimenting with the hardy bathypelagic fish *Anoplogaster cornuta*, Meek and Childress (1973) found pressure to have little effect upon oxygen consumption and suggested that some deep-living fishes are metabolically insensitive to large changes in hydrostatic pressure. Comprehensive reviews of pressure effects on living systems are provided by Knight-Jones and Morgan (1966), Morita (1967), Flügel and Schlieper (1970), Gordon (1970), Hochachka (1975), and Macdonald (1975). The problems and costs relating to maintenance of deep-living animals under hyperbaric conditions have precluded such an installation at our aquarium. The subject of high pressure aquarium systems has been discussed in a series of papers edited by R. W. Brauer (1972).

Temperature is a parameter critical to the success or failure of maintenance after capture of deep sea animals. Our preliminary data and those of others have shown that, after the initial dieoff of animals from capture-related causes, many species are able to survive at ambient pressure if their normal temperature regime is maintained. We have observed this with midwater zoarcids and liparids as have others with fishes such as *Anoplogaster* and juvenile ceratioids. Temperatures below the permanent thermocline approach levels too low to be practicably maintained using standard refrigeration units; however, we suspect that many species might become acclimated to elevated temperatures over a period of days or weeks. We have been successful in maintaining mesopelagic zoarcids at 5–6°C above the temperature of capture. Midwater collections made in higher latitudes have the advantage of passing through cold surface waters, thereby reducing the thermal stress experienced by the animals. Experiments in progress by Childress (pers. comm.) indicate that thermal stress-related mortalities can be reduced through the usage of a temperature-insulated cod end.

The intensity and quality of illumination must be carefully controlled to more nearly approach the condition of the midwater environment. Although sunlight may be measured in clear oceanic water to depths of 1000 m, the penetration through near-shelf waters is greatly reduced. Care must be taken to shield animals from bright illumination which might cause them to strike the container walls. Illumination should be weak and limited to the red hues, particularly after animals are introduced to the aquarium. Childress and Meek (1973) were able to observe and photograph *Anoplogaster cornuta* under weak red light. We have found *Melanostigma pammelas* to ignore moderate intensities of white light after being kept for several weeks.

The final parameter we have considered is oxygen. Most of the animals herein considered come from an oxygen-poor environment and all, because of the reduced temperature regime and their less active life style, have respiration rates considerably lower than related shallow water forms (Meek and Childress, 1973; Childress, 1968, 1971; Teal and Carey, 1967). For these reasons, low oxygen levels, even within a recirculating closed system, should not present a problem. Robert Meek (pers. comm.) has suggested that oxygen levels above 4 ml O_2/l may be toxic to certain mesopelagic and bathypelagic fishes. If this proves to be true, then methods such as nitrogen bubbling should be employed to reduce oxygen levels within the system.

CONCLUSIONS

The preliminary finding from SAMMP and the results of recent studies which we have outlined clearly indicate that at least some animals from mesopelagic and bathypelagic environments can be maintained in aquaria. The difficulties relating to scarcity, fragility, and light avoidance can be overcome through the development of special collecting devices and aquarium systems. The most significant finding of recent physiological studies, that temperature and not pressure is the limiting factor for many deep sea animals investigated, verifies that ambient pressure aquaria are suitable for the maintenance of these species.

In that our review of past research began with the findings of William Beebe and Otis Barton, it seems appropriate to conclude our progress report with Dr. Beebe's (1934) accounting of his observations of midwater animals made during the historic Bathysphere dives. Beebe stated that "Yet I find that I must continue to write about it, if only to prove how utterly inadequate language is to translate vividly, feeling and sensations under a condition as unique as submersion at this depth." Perhaps the time has come in which deep sea animals can be viewed and studied in aquaria.

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